Baryon Number Transport, Strangeness Conservation and Ω-hadron Correlations

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Outline

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  - Model and Energy Selection
- AMPT Data
  - Strange Quark Pair Counts
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- Hadron-Ω Correlation Function
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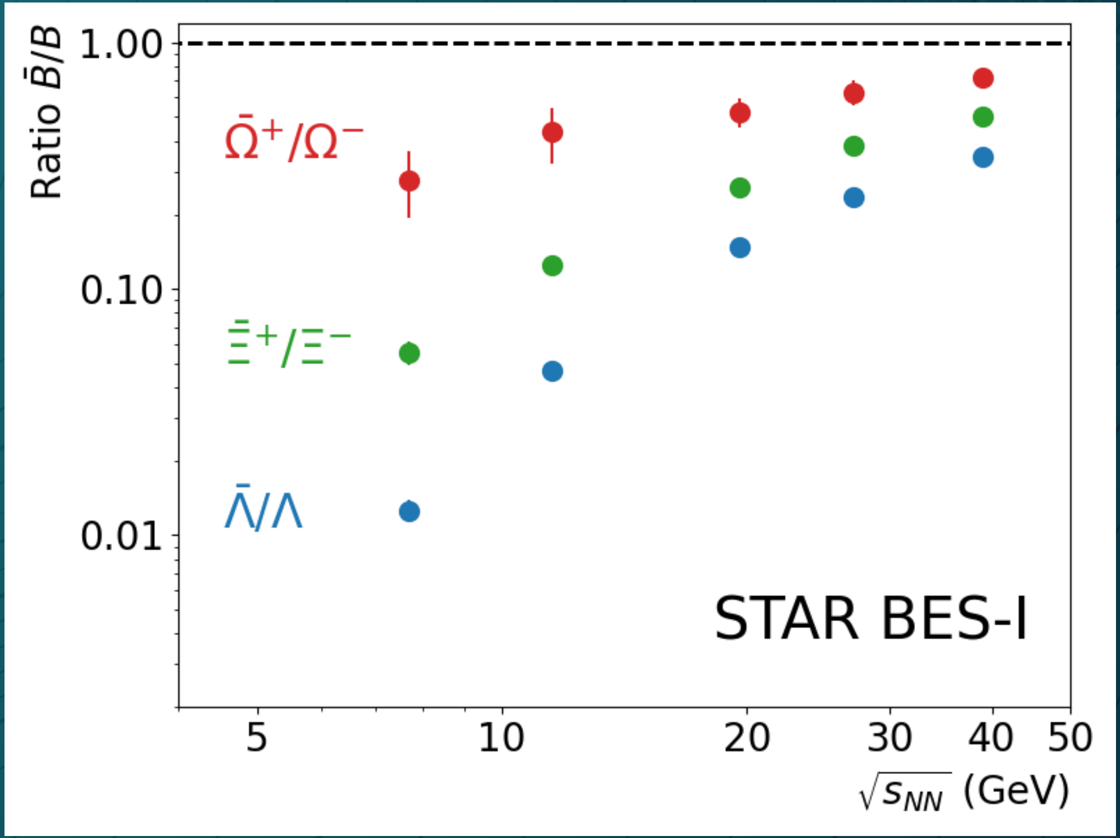
- Difference in baryon—Ω Correlations
- Summary and Outlook

Introduction

- At RHIC BES energies, below-unity $\bar{B}/B$ ratios indicate net baryons transported from the colliding nuclei
  - Λ and Ξ achieve this by carrying transported u/d quarks
  - For Ω, strangeness conservation and baryon number conservation must interplay somehow
- **How to probe quantitively the underlying mechanism?**



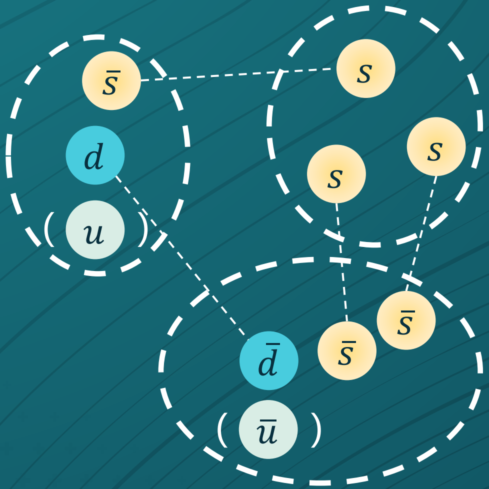
J. Adam et al. (STAR), Phys. Rev. C 102, 034909 (2020)

Strangeness Conservation (scenario 1)

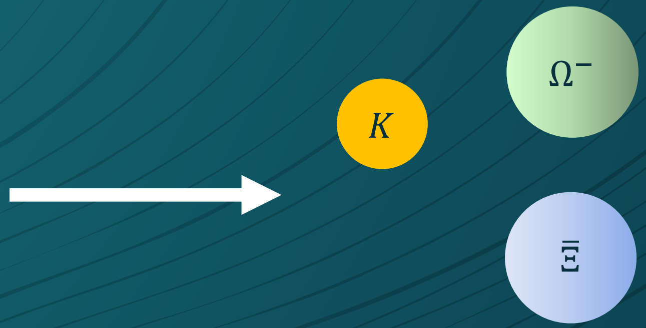
Now carries (a fraction of) baryon number from colliding nuclei!

(some u and d quarks come from colliding nuclei)

Strangeness Conservation (scenario 2)



(${u\bar{u}}$ or $d\bar{d}$ from pair production)



Can replace $\bar{\Xi}$ with $\bar{\Lambda}$, $\bar{\Sigma}$, or $\bar{p}/\bar{n}$ with one or two extra Ks

net baryon number = 0

Strangeness Conservation

Compare events with one Ω with events without any (assuming all the other non-Ω-related processes are the same), the first-order toy model gives:

- Scenario 1:
  - Ω carries baryon number from colliding nuclei
  - 3 extra K $\rightarrow \Delta N_K = 3$
  - No $\bar{B}$ correlated with Ω $\rightarrow \Delta N_{\bar{B}} = 0$
- Scenario 2:
  - Ω production not associated with net baryon number
  - 1, 2 or 3 extra K $\rightarrow \Delta N_K = 1(\bar{\Xi}), 2(\bar{\Lambda}, \bar{\Sigma}), 3(\bar{p}, \bar{n})$
  - One anti-baryon correlated with Ω $\rightarrow \Delta N_{\bar{B}} = 1$

$\Delta(\ldots) \equiv \langle \ldots \rangle_{\mathrm{w.\Omega}} - \langle \ldots \rangle_{\mathrm{w.o.\Omega}}$

$\bar{B}$ refers to $\bar{\Lambda}$, $\bar{\Sigma}$, $\bar{\Xi}$, $\bar{p}$, and $\bar{n}$

Experimental approach:
Measure $K^{\pm} - \Omega$ and $\bar{\Xi}^{+}(\bar{\Lambda}^{0}, \bar{p}) - \Omega$ correlation

Model and Energy Selection

- ΔN_K and $\Delta N_{\bar{B}}$ not all experimentally accessible (e.g., K^0)
- But model simulation can precisely count them, thus establishing baselines for more realistic experimental observables
- Need strict strangeness and baryon number conservation

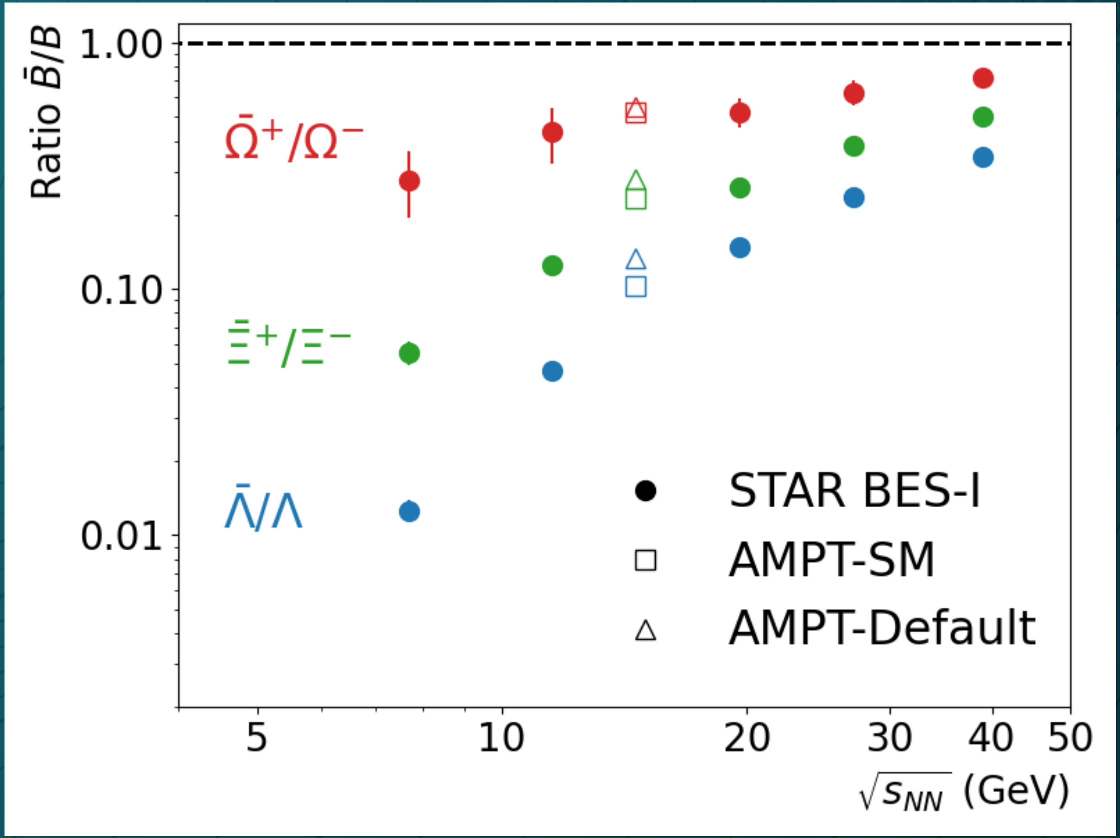
  →AMPT fits the criteria
- Restricting attention to lower RHIC BES energies (e.g., 14.6 GeV and 7.7 GeV)

  →More pronounced signatures of baryon number transport

  →Usually only one $\Omega^-/\overline{\Omega}^+$ in events with Ω, reducing dilution effects due to multiple hyperons

AMPT Data

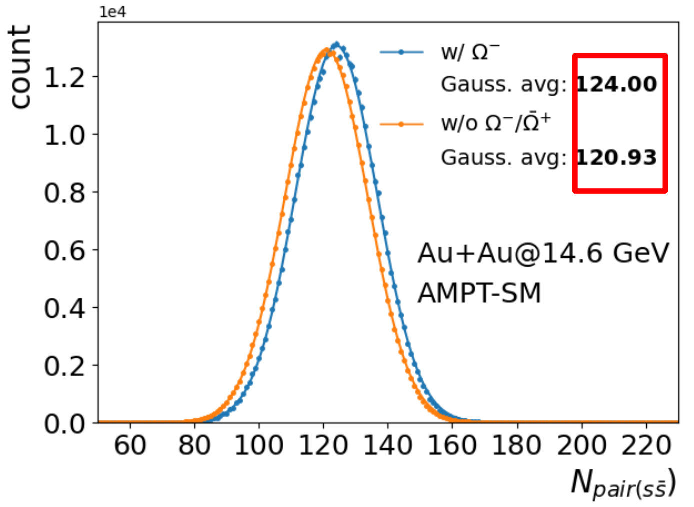
- ~100M AMPT-SM and ~50M AMPT-Default min-bias Au+Au events at 14.6 GeV
- $\bar{B}/B$ ratios in both versions agree reasonably well with BES-I results
- AMPT-Default shows higher ratios
  →Less baryon number transported?

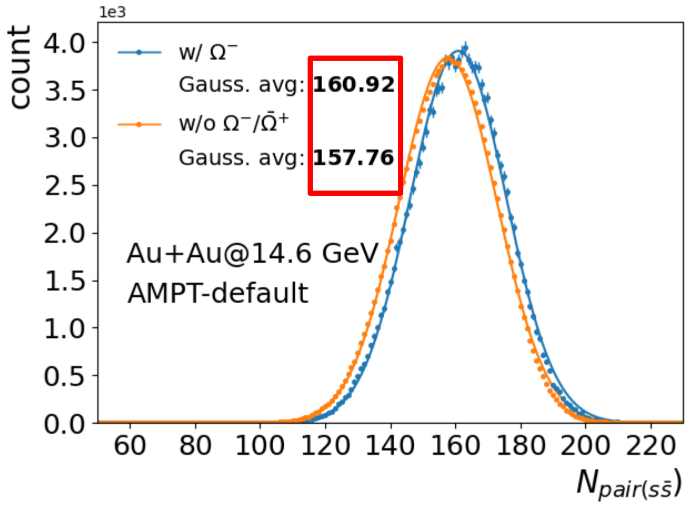


J. Adam et al. (STAR), Phys. Rev. C 102, 034909 (2020)

Strange Quark Pair Counts

- Number of $s\bar{s}$ pair difference between events with Ω and events without any is close to 3 in both AMPT versions on average
  →Difference mostly due to Ω and associated strange hadron production
- This suggests small difference in the non-Ω related processes between events with one Ω and events without any
  →We can directly subtract one from another to get the ΔN_K and $\Delta N_{\bar{B}}$
- AMPT-Default produce about 20% more $s\bar{s}$ pairs on average





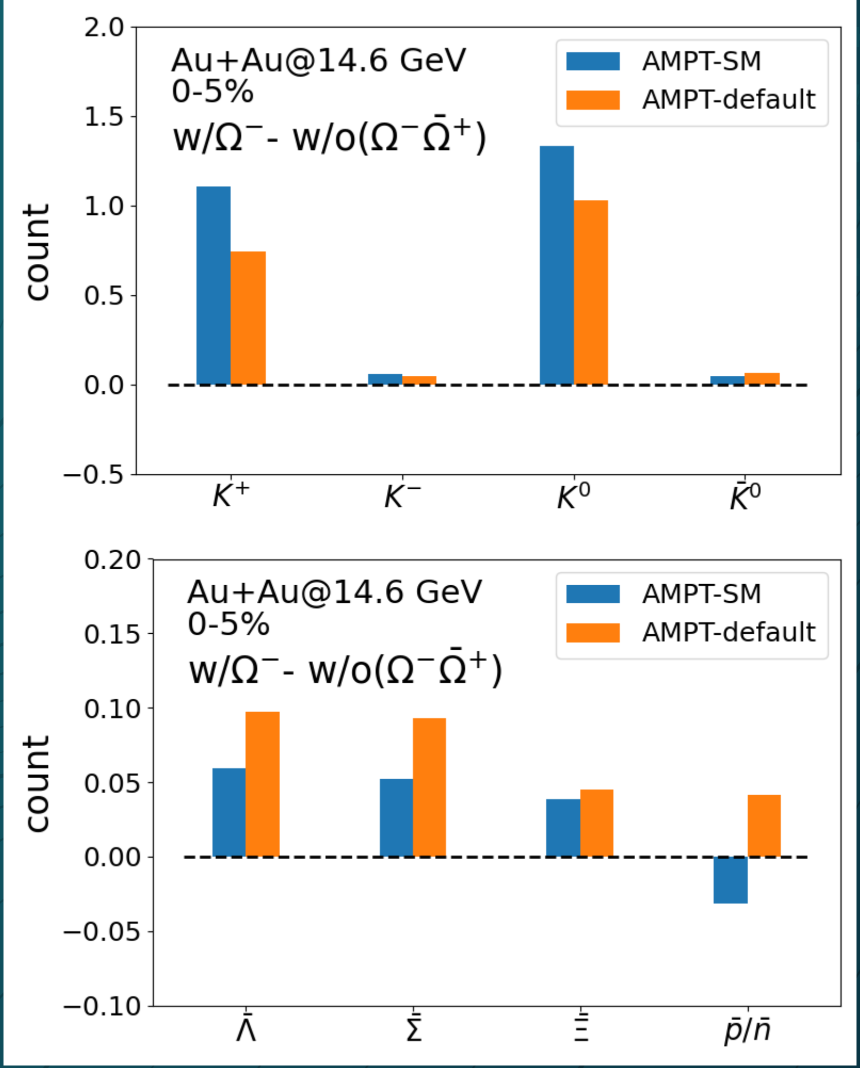
Strange Hadron Counts

In the white bracket: with STAR η acceptance

- AMPT-SM:
  - $\Delta N_K \approx 2.44$ ($\Delta N_{K^+} \approx 0.29$) (3 for scenario 1)
  - $\Delta N_{\bar{B}} \approx 0.12$ (0.04) (0 for scenario 1)

AMPT-Default:
  - $\Delta N_K \approx 1.76$ ($\Delta N_{K^+} \approx 0.26$) (1-3 for scenario 2)
  - $\Delta N_{\bar{B}} \approx 0.28$ (0.14) (1 for scenario 2)

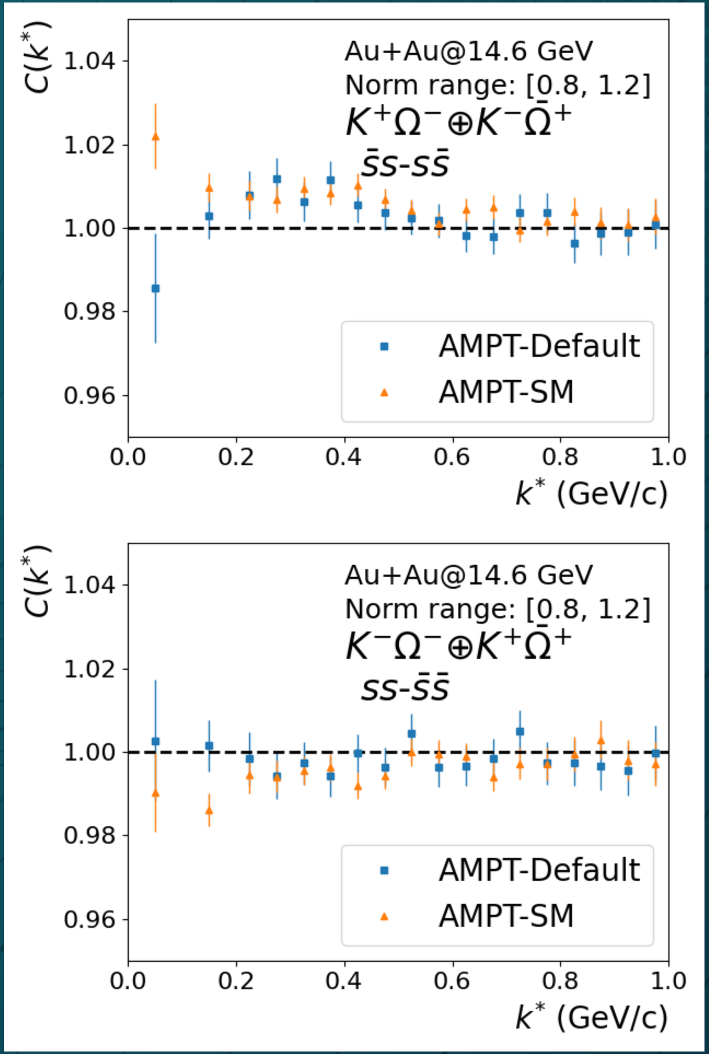
- Both models exhibit a mixture of the two scenarios but AMPT-SM favors scenario 1



Hadron-Ω Correlation

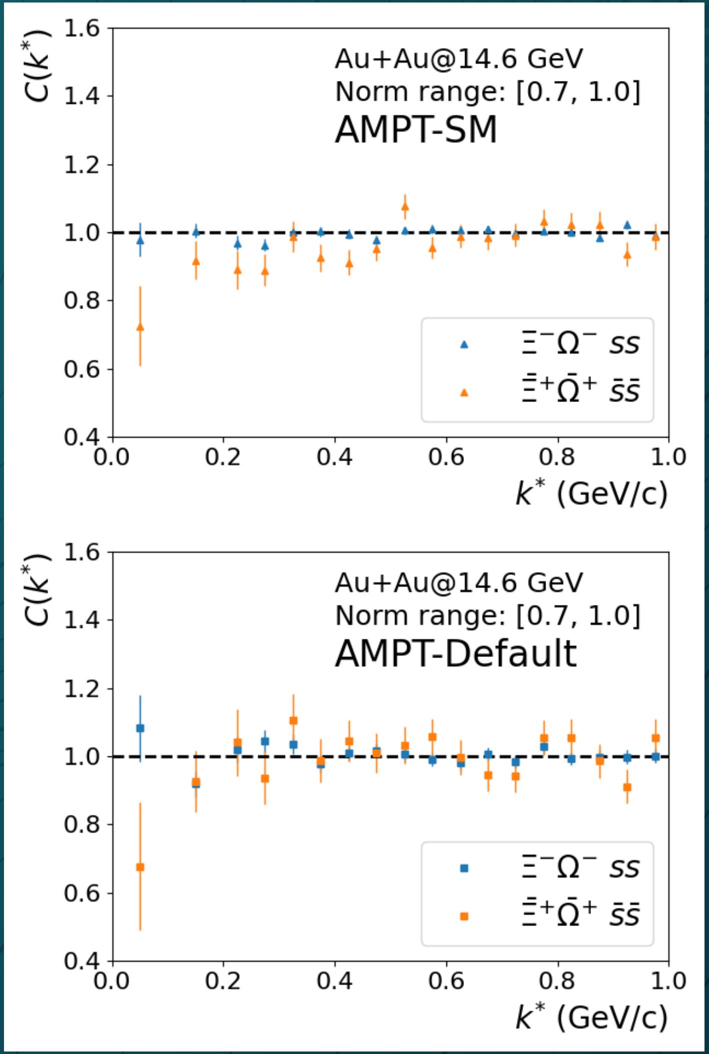
- $C(k^*) = A(k^*)/B(k^*)$
  - $A(k^*)$: same-event distribution
    $B(k^*)$: mixed-event distribution
  - $k^* = |p_1{}^* - p_2{}^*|/2$
    $p_{1,2}{}^*$: pair-rest-frame momenta
- Event selection: 0-5% events w/ exactly one Ω^- or $\overline{\Omega}^+$

  Track cut: $|\eta| < 1$
- Two "same-sign" combinations consistent with each other, also true for "opposite-sign"
- **Potential difference between models at low k^***



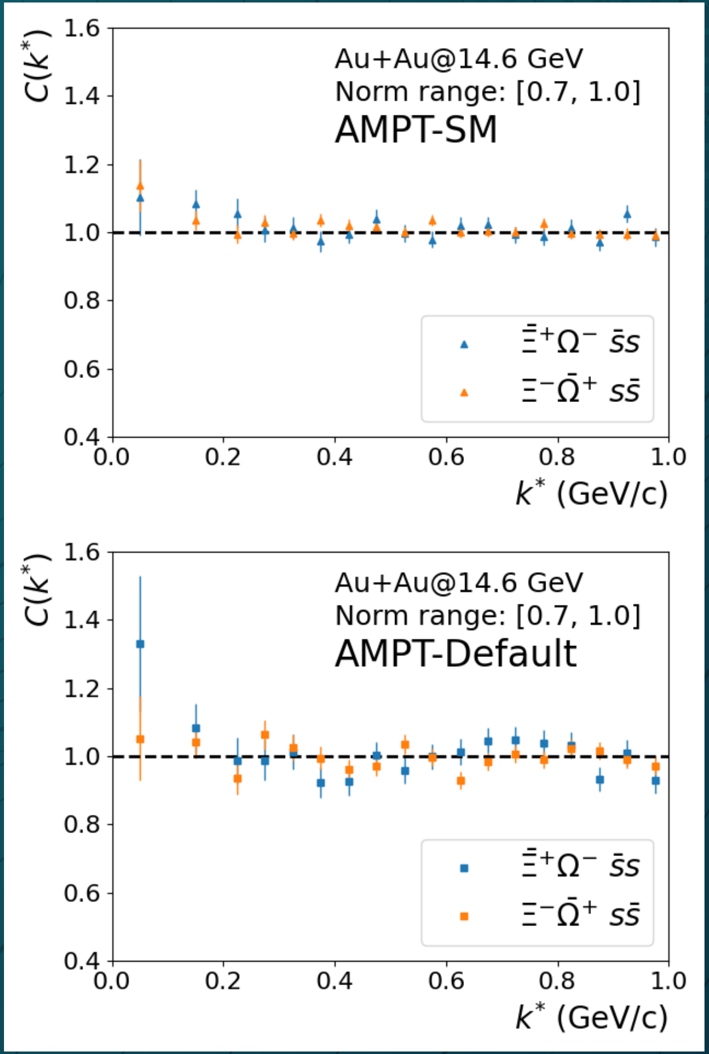
Hadron-Ω Correlation

- $\Xi - \Omega$ correlation show some dependence on net-baryon number
- **Similar for the two AMPT versions in same-sign correlations**



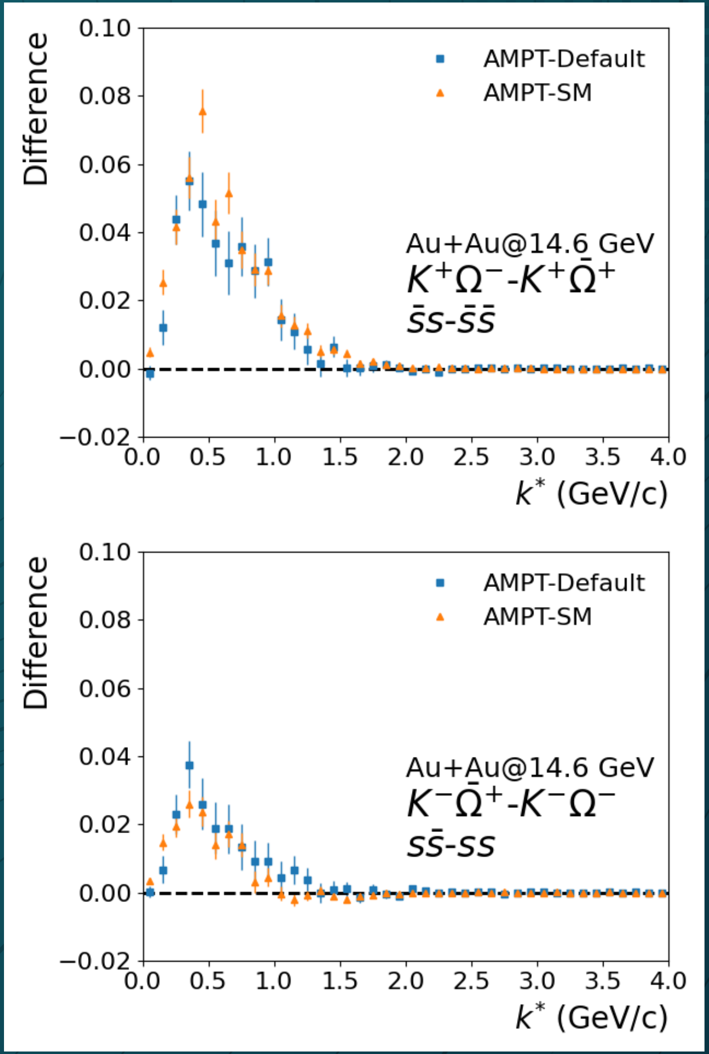
Hadron-Ω Correlation

- $\Xi - \Omega$ correlation show some dependence on net-baryon number
- **Similar for the two AMPT versions in same-sign correlations**
- **Potential $\bar{\Xi}^{+} - \Omega$ correlation due to scenario 2**



Difference in $K^{\pm} - \Omega$ Correlation

- Idea: opposite sign minus same-sign, $s\bar{s} - s(\bar{s})s(\bar{s})$
  - e.g., $K^{+}\Omega^{-} - K^{+}\overline{\Omega}^{+}$ and $K^{-}\overline{\Omega}^{+} - K^{-}\Omega^{-}$
  - Same event and track selection
  - Normalized by number of events, not by event-mixing
- **Shows effects of transported quarks**



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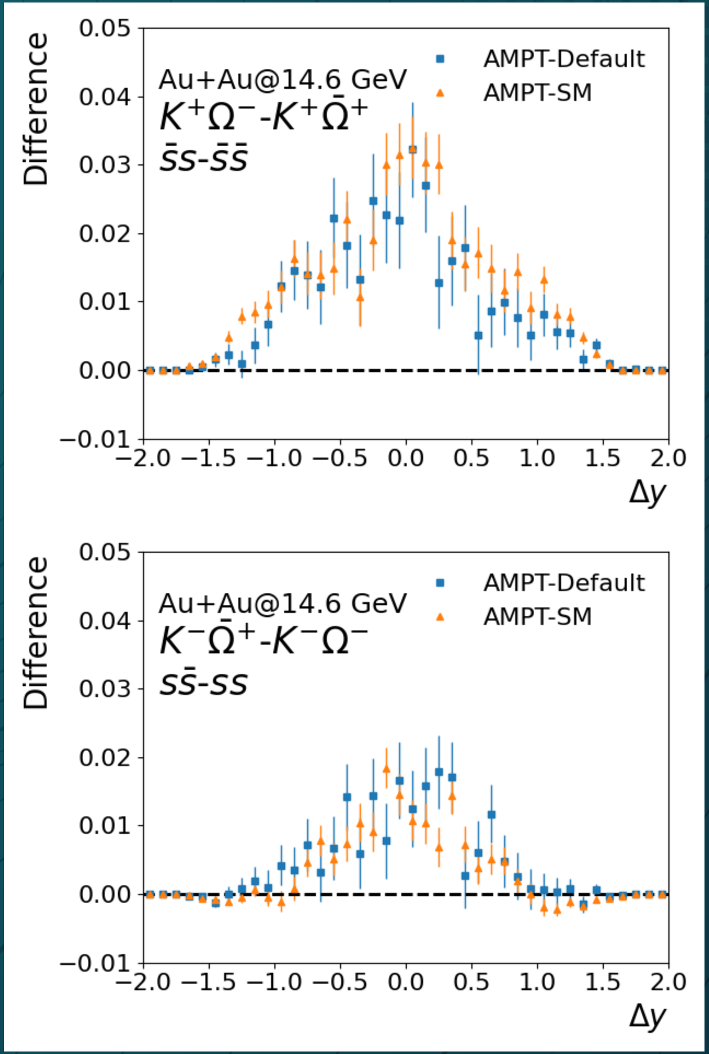

Difference in $K^{\pm} - \Omega$ Correlation

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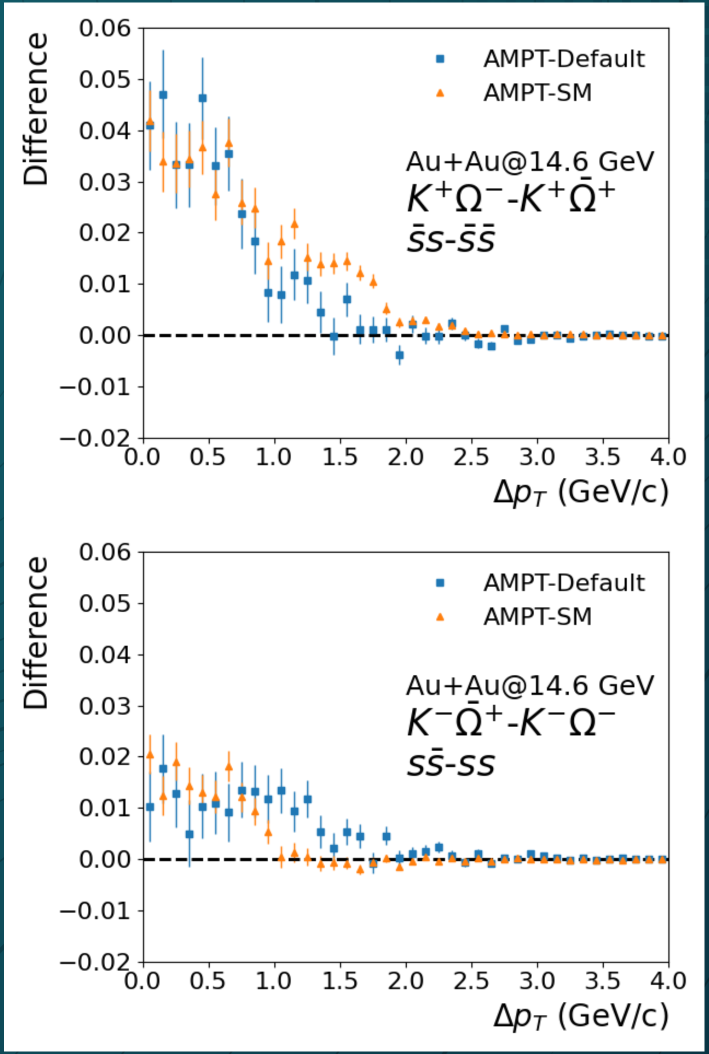
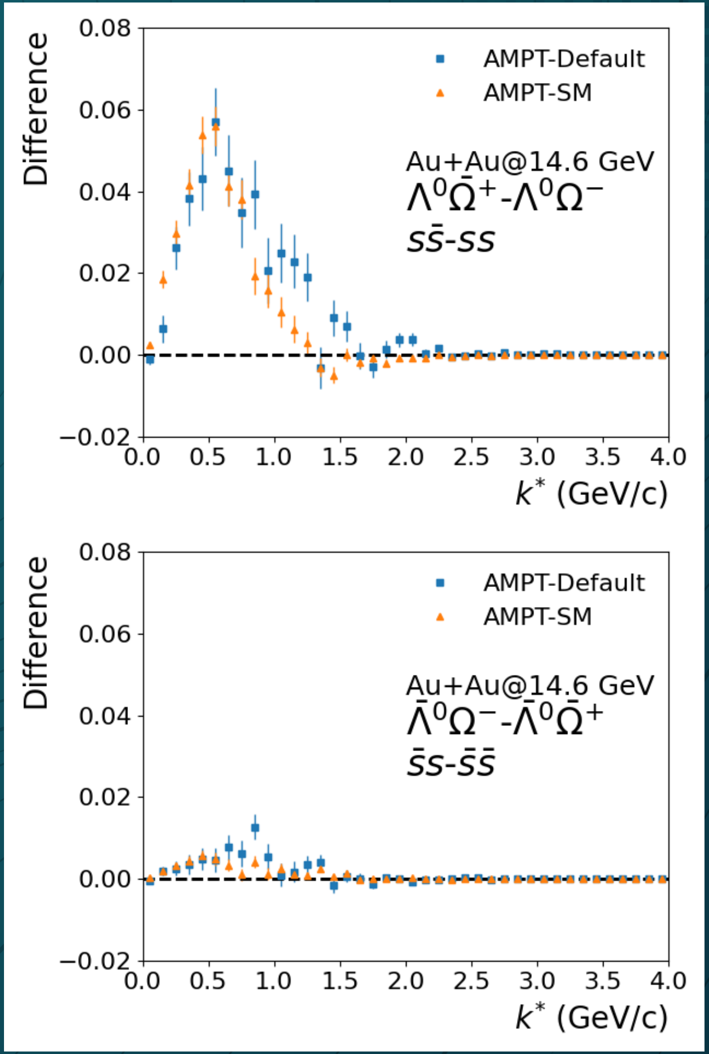
  - Same event and track selection
  - Normalized by number of events, not by event-mixing
- **Shows effects of transported quarks**
- **Two AMPT versions show no significant difference in the shape of the intrinsic $s\bar{s}$ correlations**
- **But some difference in Δp_T correlation widths**



Difference in baryon–Ω Correlation

- Idea: opposite-sign minus same-sign, $s\bar{s} - s(\bar{s})s(\bar{s})$
  - e.g., $\overline{\Lambda}^0\Omega^- - \overline{\Lambda}^0\overline{\Omega}^+$ and $\Lambda^0\overline{\Omega}^+ - \Lambda^0\Omega^-$
  - Same event and track selection
- **Two AMPT versions show noticeable difference in $s\bar{s}$ correlation widths**

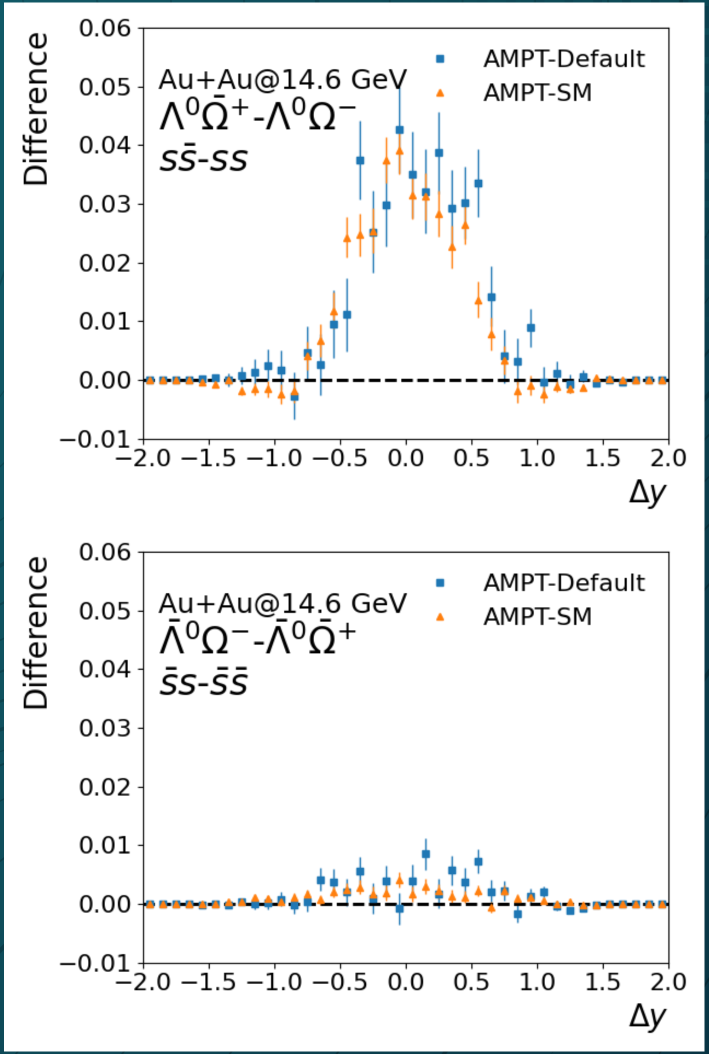
  →Does such difference relate to the two Ω production scenarios?
- **Again shows effects of transported quarks**



Difference in baryon–Ω Correlation

- Idea: opposite-sign minus same-sign, $s\bar{s} - s(\bar{s})s(\bar{s})$
  - e.g., $\bar{\Lambda}^0\Omega^- - \bar{\Lambda}^0\bar{\Omega}^+$ and $\Lambda^0\bar{\Omega}^+ - \Lambda^0\Omega^-$
  - Same event and track selection
- **Two AMPT versions show noticeable difference in $s\bar{s}$ correlation widths**

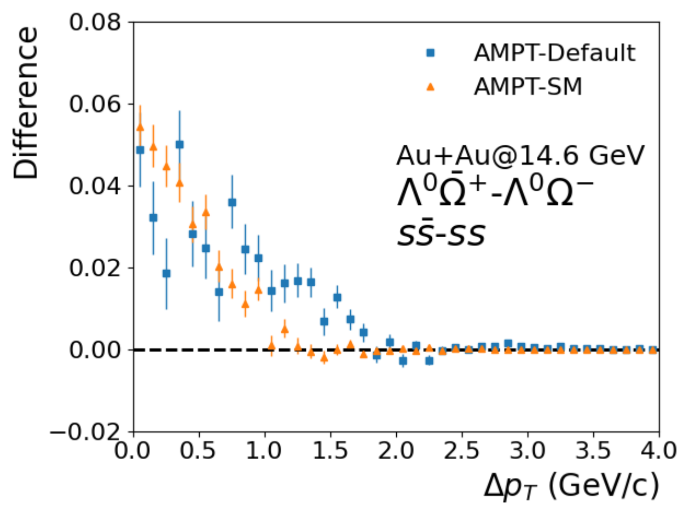
  →Does such difference relate to the two Ω production scenarios?
- **Again shows effects of transported quarks**

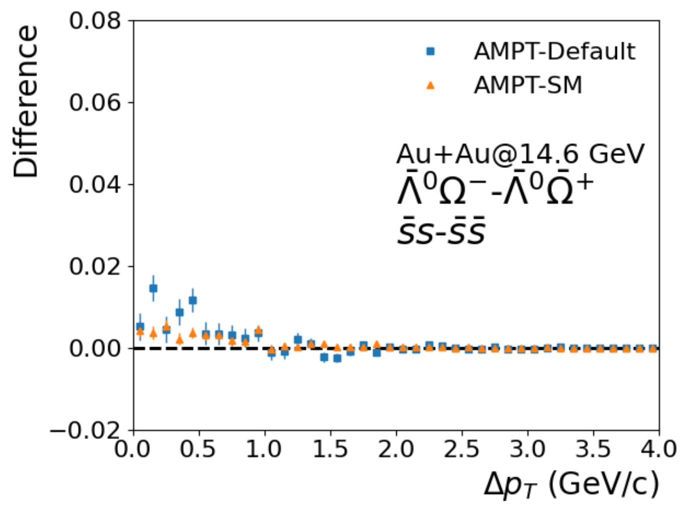


Difference in baryon—Ω Correlation

- Idea: opposite-sign minus same-sign, $s\bar{s} - s(\bar{s})s(\bar{s})$
  - e.g., $\overline{\Lambda}^0\Omega^- - \overline{\Lambda}^0\overline{\Omega}^+$ and $\Lambda^0\overline{\Omega}^+ - \Lambda^0\Omega^-$
  - Same event and track selection
- **Two AMPT versions show noticeable difference in $s\bar{s}$ correlation widths**

  →Does such difference relate to the two Ω production scenarios?
- **Again shows effects of transported quarks**





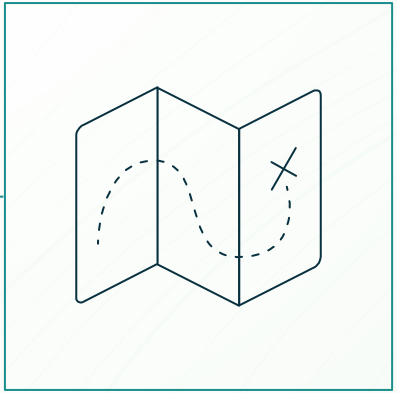
Summary

- Two scenarios of Ω production that conserve strangeness
- Kaon and anti-baryon counts suggest a mixture of scenarios for both AMPT versions; SM favors scenario 1 and Default favors scenario 2
- Two AMPT versions show potential difference in $K^{\pm} - \Omega$, with possible $\bar{\Xi}^{+} - \Omega$ peak
- In the correlation difference, two AMPT versions show similar intrinsic $s\bar{s}$ correlation shape, with slight difference in correlation widths
- By looking at $K - \Omega$ and hyperon$-\Omega$ correlations, we can probe the particle formation mechanisms and study the effects of strangeness conservation and baryon number transport at RHIC BES energies

Outlook

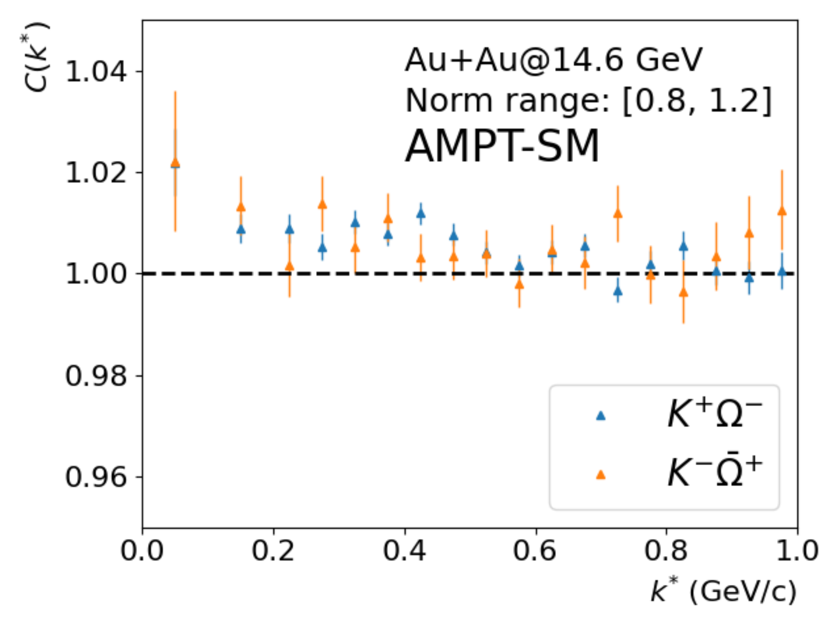
- Increase statistics
- Incorporate 7.7 GeV AMPT data with empirically higher hadronic degree of freedom
- Use new AMPT with an improved quark coalescence*
- Move from simulation to real data analysis, considering correction for efficiency and acceptance

* Y. He and Z. W. Lin, Phys. Rev C 96, 014910 (2017)

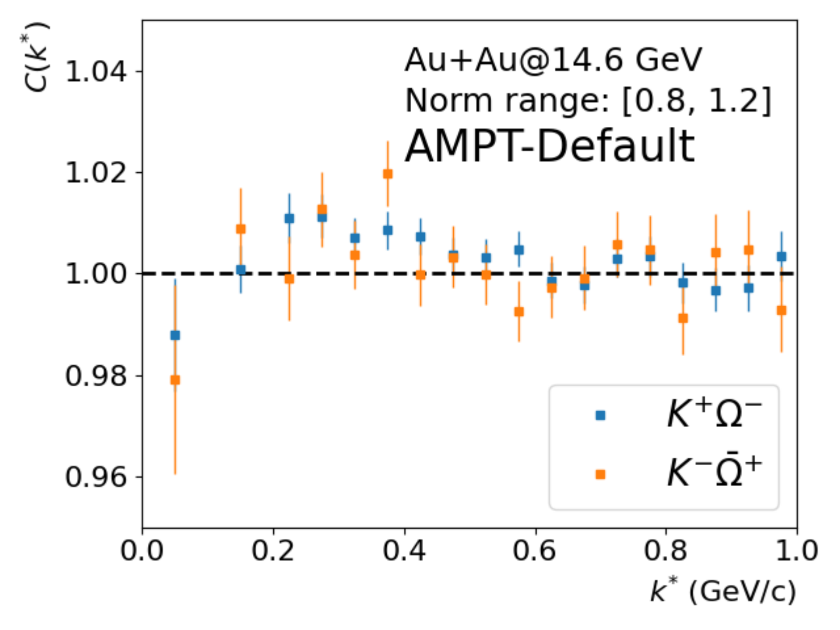


Thanks!

Backup

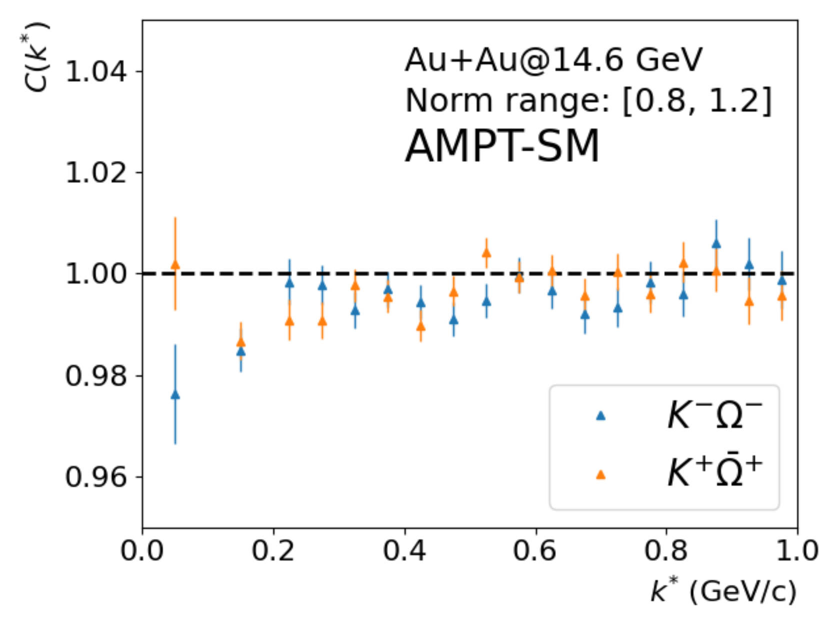


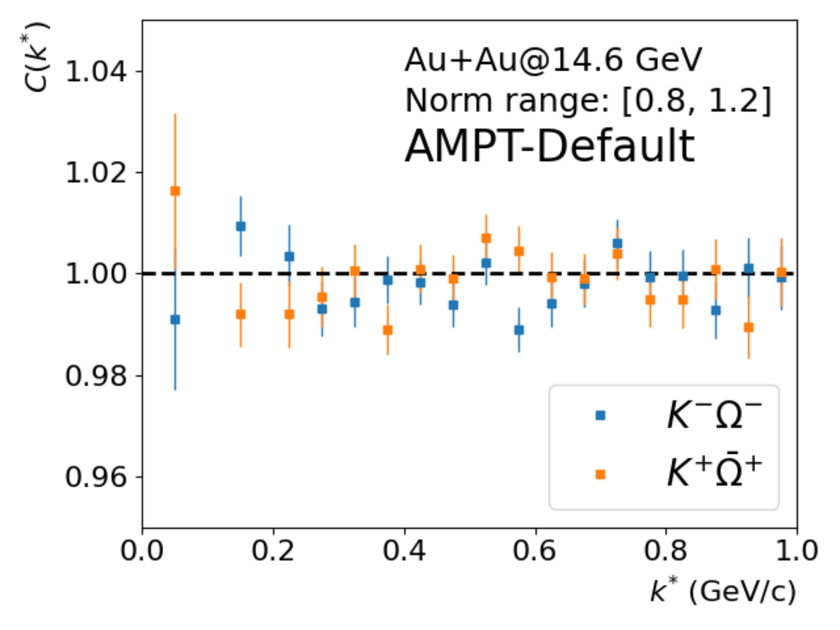
Au+Au@14.6 GeV
Norm range: [0.8, 1.2]
AMPT-SM
$C(k^*)$
k^* (GeV/c)
$K^+\Omega^-$
$K^-\bar{\Omega}^+$



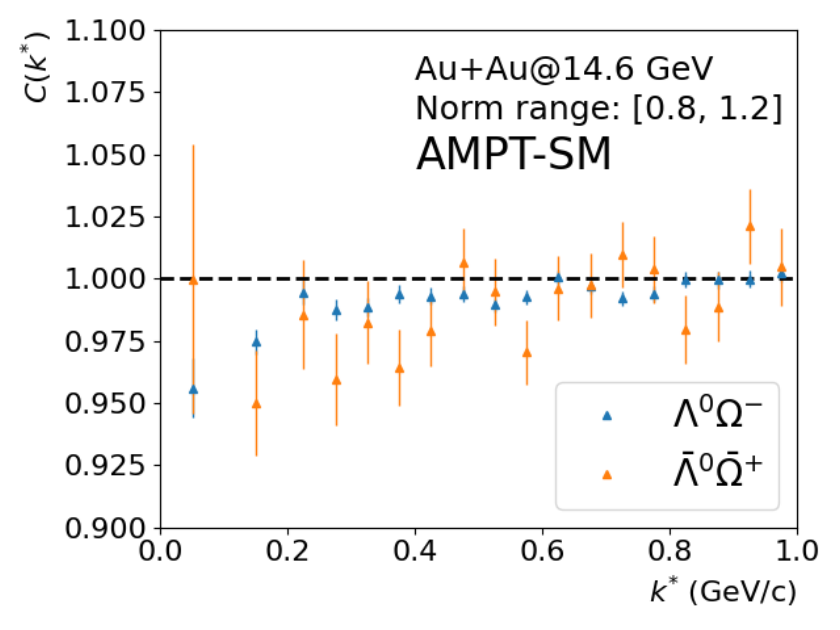
Au+Au@14.6 GeV
Norm range: [0.8, 1.2]
AMPT-Default
$C(k^*)$
k^* (GeV/c)
$K^+\Omega^-$
$K^-\bar{\Omega}^+$

Backup

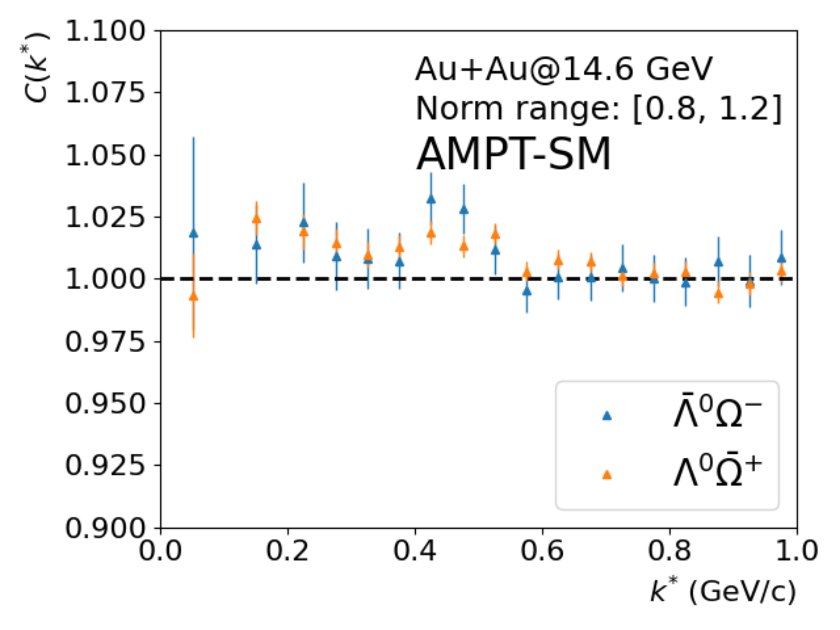

Au+Au@14.6 GeV
Norm range: [0.8, 1.2]
AMPT-SM
$K^-\Omega^-$
$K^+\bar{\Omega}^+$
$C(k^*)$
k^* (GeV/c)


Au+Au@14.6 GeV
Norm range: [0.8, 1.2]
AMPT-Default
$K^-\Omega^-$
$K^+\bar{\Omega}^+$
$C(k^*)$
k^* (GeV/c)

Backup

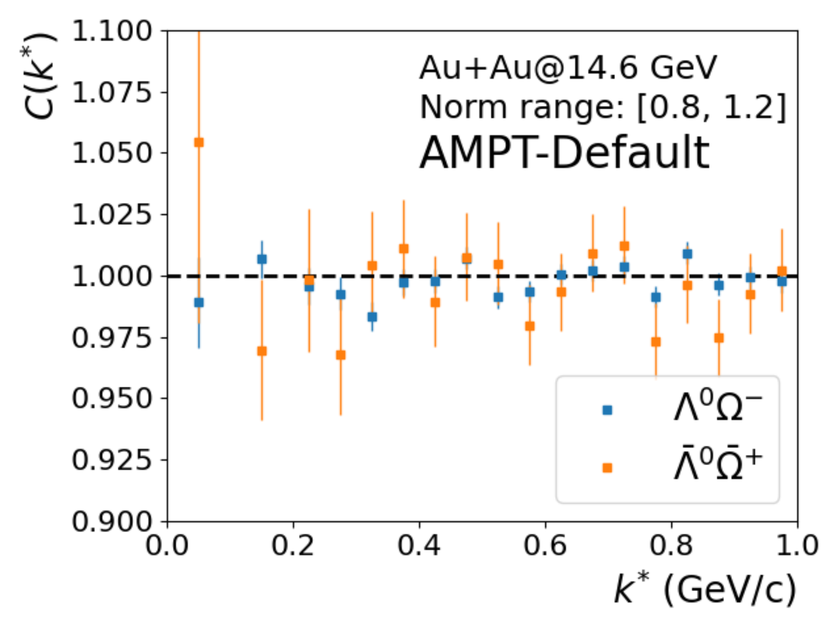


Au+Au@14.6 GeV
Norm range: [0.8, 1.2]
AMPT-SM
$\Lambda^0\Omega^-$
$\bar{\Lambda}^0\bar{\Omega}^+$
$C(k^*)$
k^* (GeV/c)

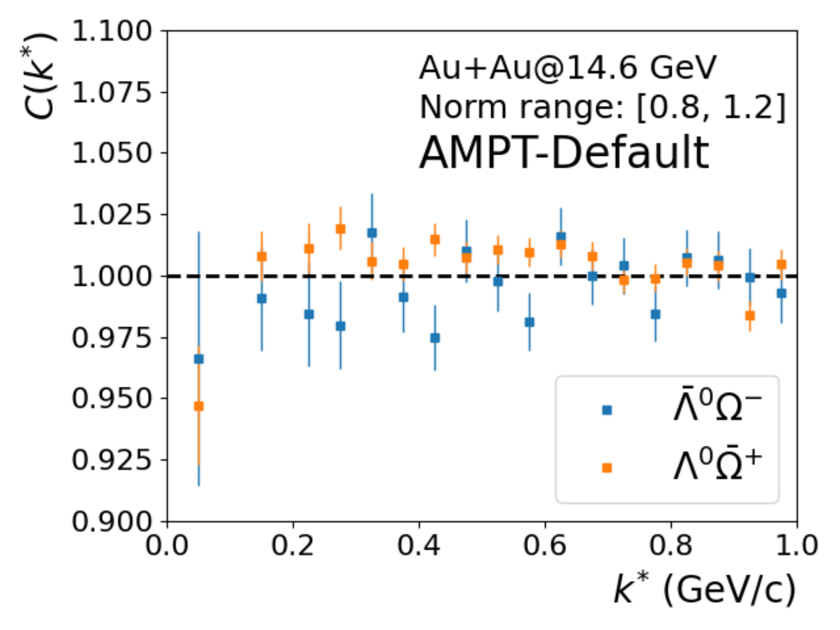


Au+Au@14.6 GeV
Norm range: [0.8, 1.2]
AMPT-SM
$\bar{\Lambda}^0\Omega^-$
$\Lambda^0\bar{\Omega}^+$
$C(k^*)$
k^* (GeV/c)

Backup

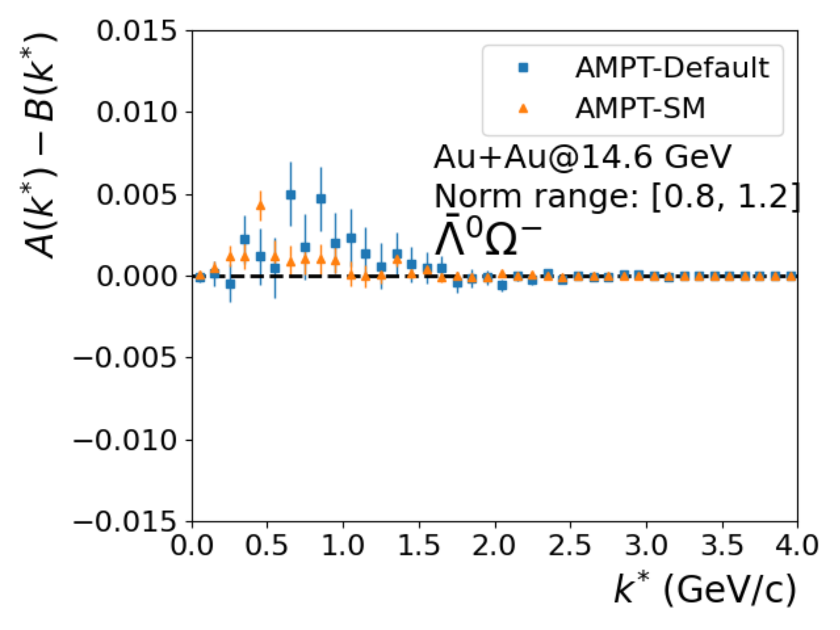


Au+Au@14.6 GeV
Norm range: [0.8, 1.2]
AMPT-Default
$\Lambda^0\Omega^-$
$\bar{\Lambda}^0\bar{\Omega}^+$
$C(k^*)$
k^* (GeV/c)
1.100
1.075
1.050
1.025
1.000
0.975
0.950
0.925
0.900
0.0
0.2
0.4
0.6
0.8
1.0

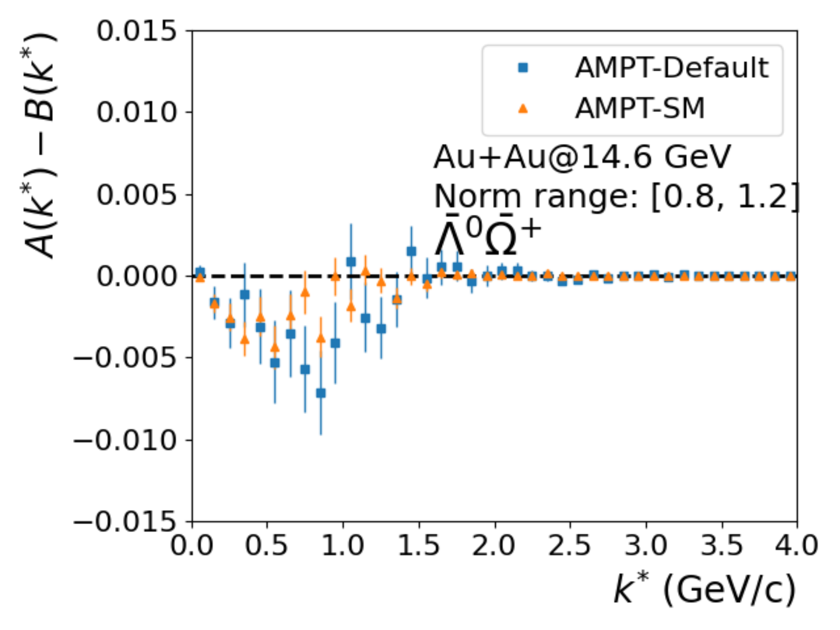


Au+Au@14.6 GeV
Norm range: [0.8, 1.2]
AMPT-Default
$\bar{\Lambda}^0\Omega^-$
$\Lambda^0\bar{\Omega}^+$
$C(k^*)$
k^* (GeV/c)
1.100
1.075
1.050
1.025
1.000
0.975
0.950
0.925
0.900
0.0
0.2
0.4
0.6
0.8
1.0

Backup

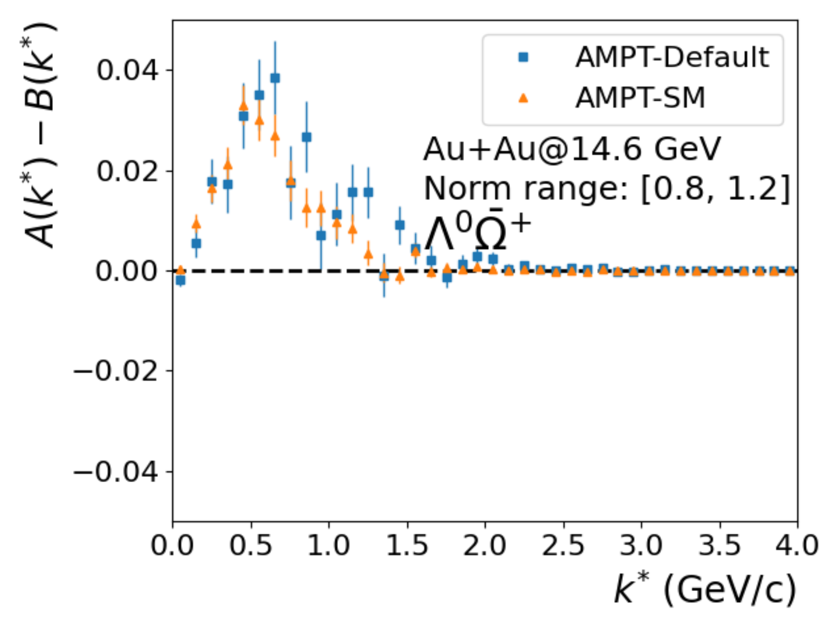


0.015
0.010
0.005
0.000
−0.005
−0.010
−0.015
0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0
$A(k^*) - B(k^*)$
k^* (GeV/c)
AMPT-Default
AMPT-SM
Au+Au@14.6 GeV
Norm range: [0.8, 1.2]
$\bar{\Lambda}^0\Omega^-$

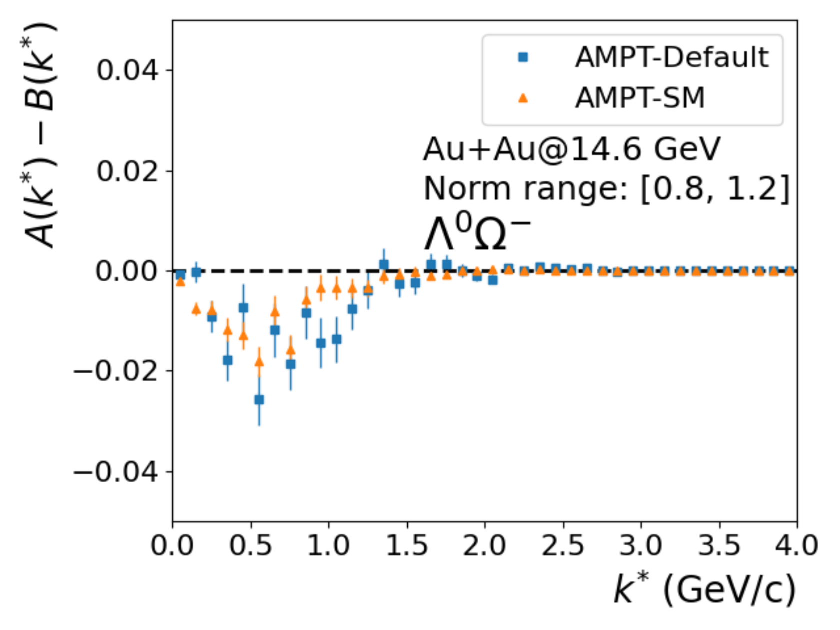


0.015
0.010
0.005
0.000
−0.005
−0.010
−0.015
0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0
$A(k^*) - B(k^*)$
k^* (GeV/c)
AMPT-Default
AMPT-SM
Au+Au@14.6 GeV
Norm range: [0.8, 1.2]
$\bar{\Lambda}^0\bar{\Omega}^+$

Backup

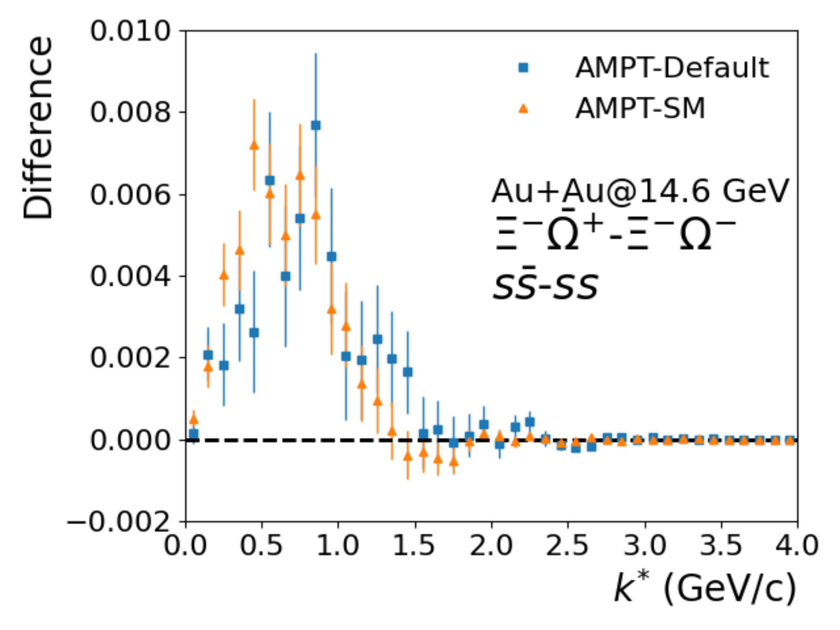


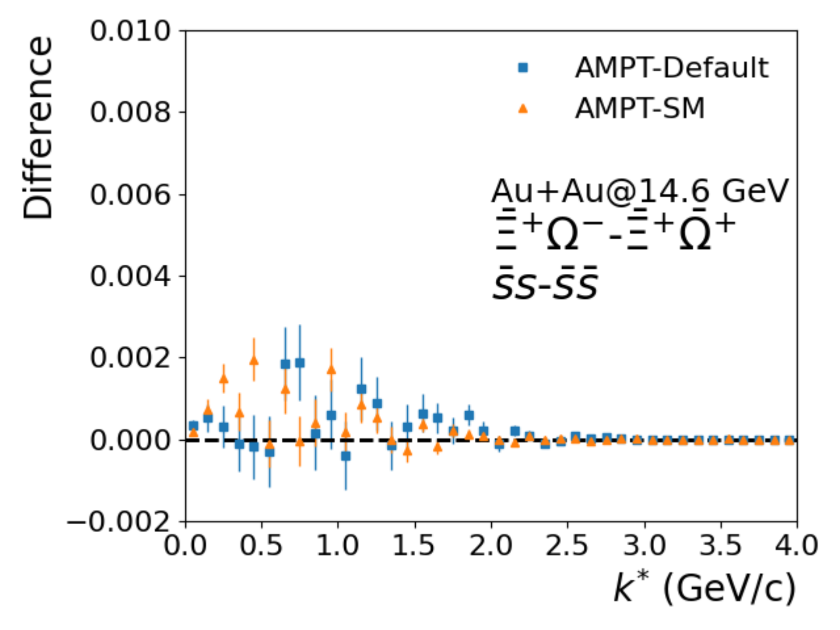
A(k*) − B(k*)
0.04
0.02
0.00
−0.02
−0.04
0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0
k* (GeV/c)
AMPT-Default
AMPT-SM
Au+Au@14.6 GeV
Norm range: [0.8, 1.2]
$\Lambda^0\bar{\Omega}^+$



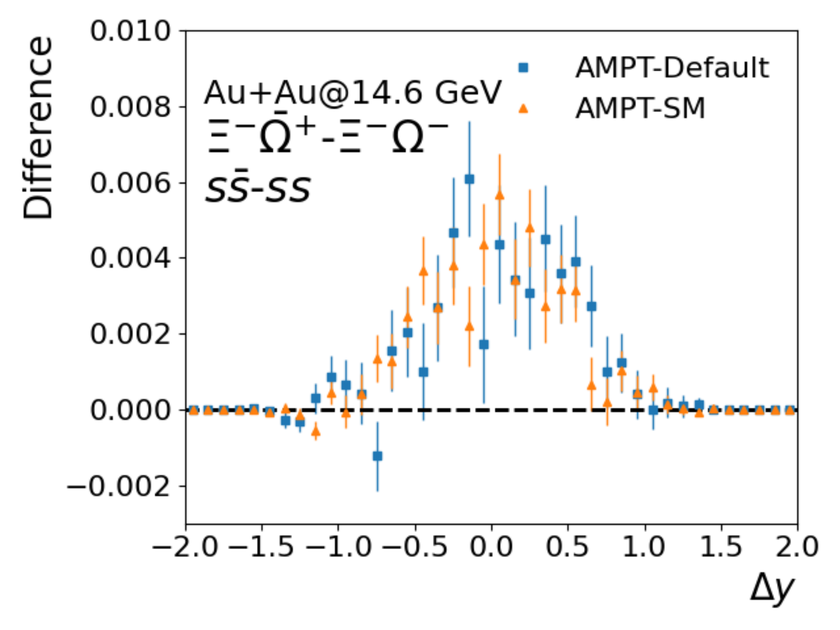
A(k*) − B(k*)
0.04
0.02
0.00
−0.02
−0.04
0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0
k* (GeV/c)
AMPT-Default
AMPT-SM
Au+Au@14.6 GeV
Norm range: [0.8, 1.2]
$\Lambda^0\Omega^-$

Backup

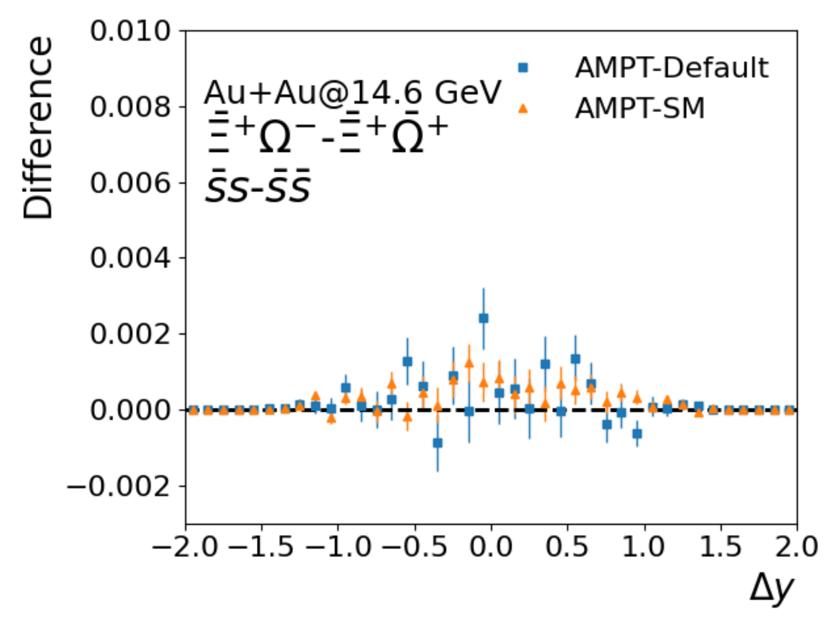

Difference
0.010
0.008
0.006
0.004
0.002
0.000
−0.002
0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0
AMPT-Default
AMPT-SM
Au+Au@14.6 GeV
$\Xi^-\bar{\Omega}^+$-$\Xi^-\Omega^-$
$s\bar{s}$-ss
k^* (GeV/c)


Difference
0.010
0.008
0.006
0.004
0.002
0.000
−0.002
0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0
AMPT-Default
AMPT-SM
Au+Au@14.6 GeV
$\bar{\Xi}^+\Omega^-$-$\bar{\Xi}^+\bar{\Omega}^+$
$\bar{s}s$-$\bar{s}\bar{s}$
k^* (GeV/c)

Backup

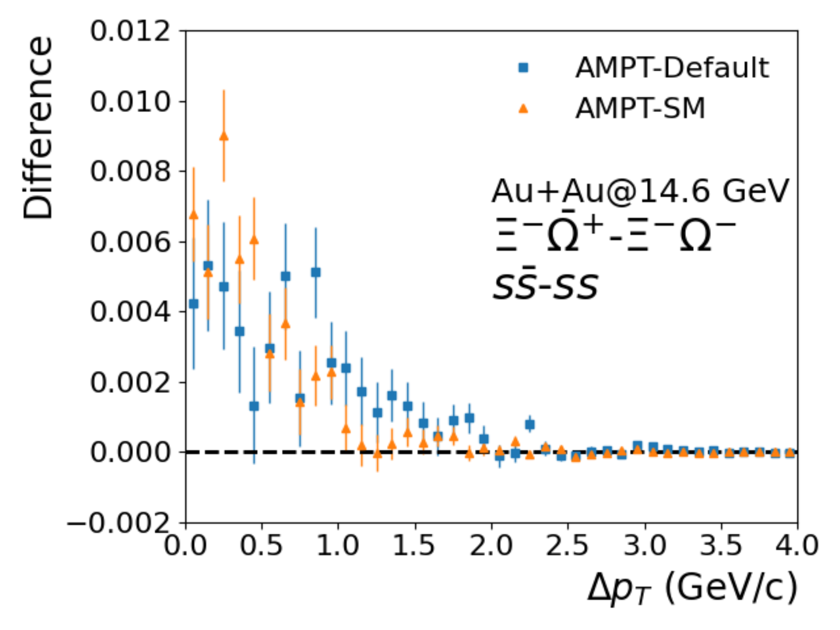


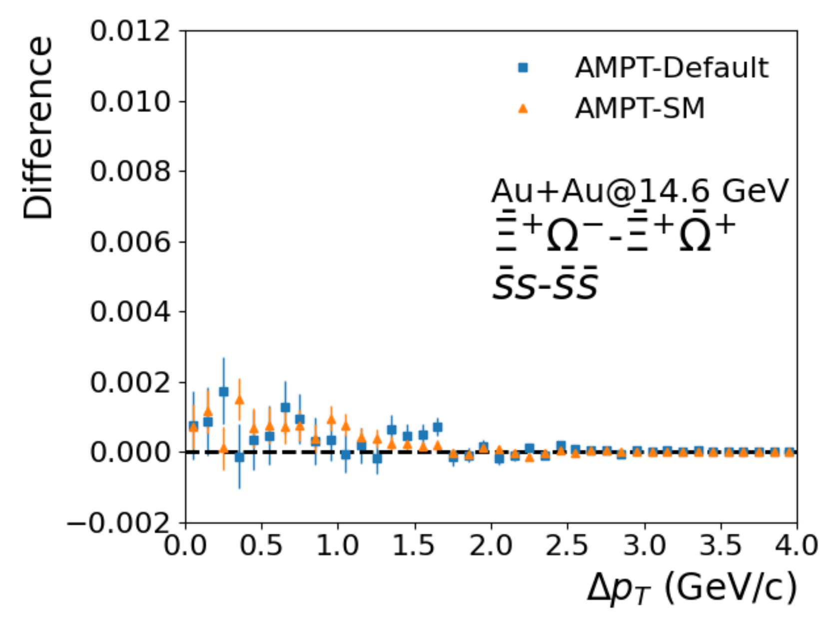
Au+Au@14.6 GeV
$\Xi^-\bar{\Omega}^+$-$\Xi^-\Omega^-$
$s\bar{s}$-ss
AMPT-Default
AMPT-SM
Difference
Δy



Au+Au@14.6 GeV
$\bar{\Xi}^+\Omega^-$-$\bar{\Xi}^+\bar{\Omega}^+$
$\bar{s}s$-$\bar{s}\bar{s}$
AMPT-Default
AMPT-SM
Difference
Δy

Backup


AMPT-Default
AMPT-SM
Au+Au@14.6 GeV
$\Xi^-\bar{\Omega}^+$-$\Xi^-\Omega^-$
$s\bar{s}$-ss
Difference
Δp_T (GeV/c)


AMPT-Default
AMPT-SM
Au+Au@14.6 GeV
$\bar{\Xi}^+\Omega^-$-$\bar{\Xi}^+\bar{\Omega}^+$
$\bar{s}s$-$\bar{s}\bar{s}$
Difference
Δp_T (GeV/c)